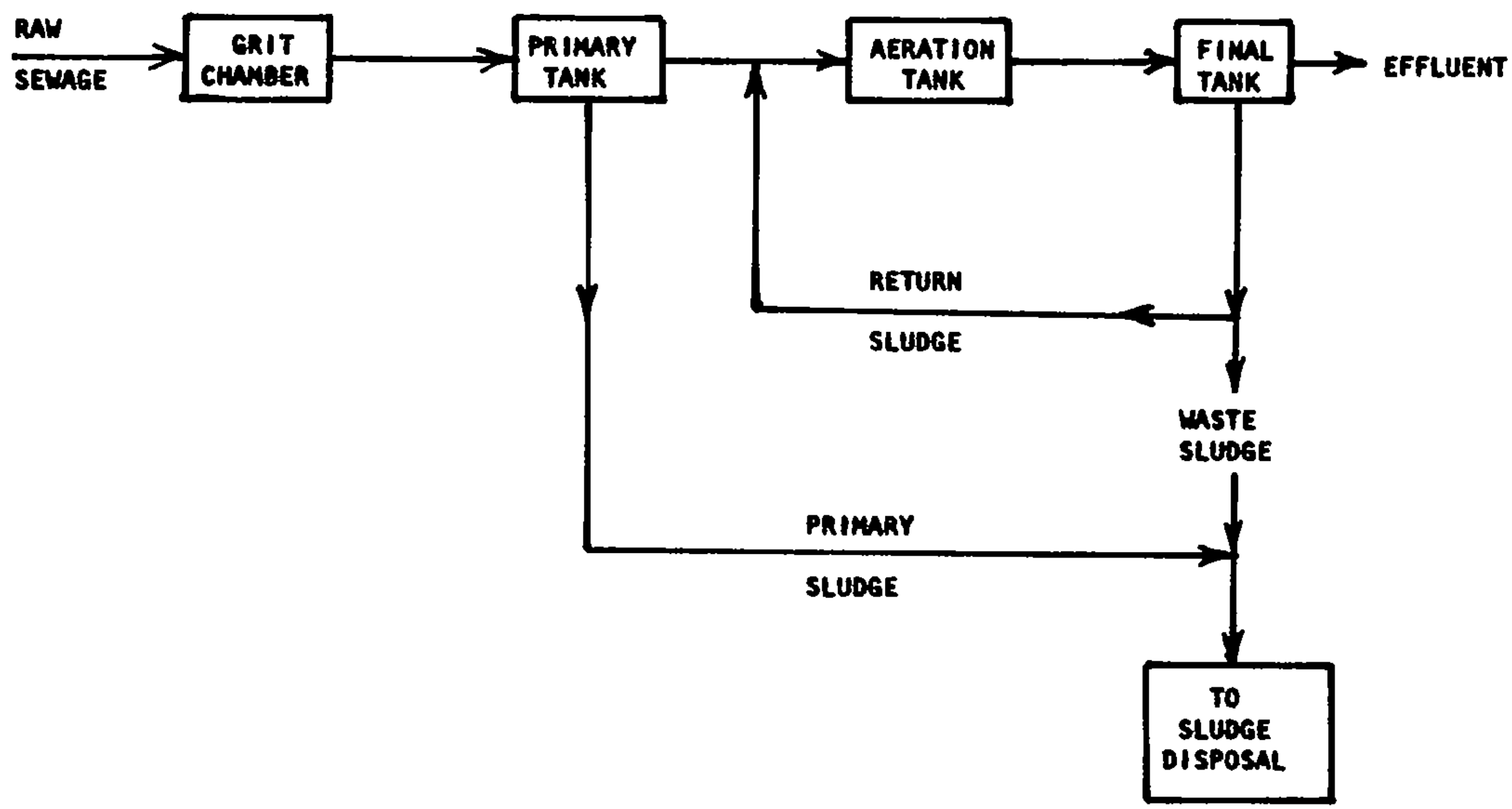


Figure 3. Conventional activated sludge plant.

TABLE 8. SUMMARY OF DESIGN AND OPERATIONAL PARAMETERS FOR VARIOUS DRY WEATHER TREATMENT PROCESSES (16)(17)(18)(19)

Treatment process	Hydraulic Overflow rate l/min/sq m (gpm/sq ft)	Suspended Solids loading kg/day/sq m (lb/day/sq ft)	Organic loading kg BOD/day kg MLSS	Detention time	Sludge produced cu m/1000 cu m (cu ft/MG)	% Sludge solids	Effluent SS mg/l
Grit removal (0.2 mm, SP. Gr. 2.65)	1258 (30.9)	- -	-	30-60 sec	0.01-0.09 (1-12)	-	-
Plain sedimentation	16-65 (0.4-1.6)	2.4-9.8 (0.5-2.0)	-	1.5.2-5 hr	2.43 (325)	5	80-120
Aeration	- -	- -	0.35-0.50	6-8 hr	-	-	-
Final sedimentation	10-31 (0.25-0.75)	98-146 (20-30)	-	2-3 hr	18.7	0.5-1.5	10-50

The treatment scheme shown in Figure 3 is the minimum required in the near future, and is one which is in common use today. It should be recognized that many existing treatment plants are not capable of meeting the more stringent performance levels required today [See Table 7 and compare final clarification effluent suspended solids content expected (10-50 mg/l) with that presently required (30 mg/l)]. Moreover, meeting additional regulatory agency stipulations, such as (1) more stringent disinfection requirements, (2) phosphorus removal and (3) partial or complete oxidation of ammonia nitrogen or high nitrogen removal, will require significant expansion and/or modification of existing facilities.

Sludge handling should be considered an integral part of the total waste treatment process. Although the volume of dry weather residual sludges obtained is relatively small, usually 2% to 3% of the wastewater volume treated, sludge handling and disposal is complex, troublesome, and represents up to 25% to 50% of the capital and operating costs of a waste treatment plant (20). Moreover, the problem is growing. With the expansion of the economy and the population and with the greater degree of treatment required, it is expected, within the next 5 to 10 years, that the volume of sludge requiring handling and disposal will increase by 60% to 70% (20). By far, the major portion of the increased sludge volume expected will be obtained from secondary treatment sludges, which are less concentrated than primary sludges, and which are most difficult and expensive to treat. For example, in 1980 it is anticipated that 530,000 cu m/day (140 MGD) of secondary sludge (2% solids) will be produced, whereas only about 37,850 cu m/day (10 MGD) of primary sludge (6% solids) are expected in that year (21).

The various steps leading to the ultimate disposal of the residual sludges are presented, schematically, in Figure 4. From Figure 4, sludge handling for ultimate disposal consists of a series of dewatering steps in which the volume of sludge is progressively reduced by removal of the water associated with the sludge solids.

Thickening is usually the first step in sludge handling and is responsible for removing the major portion of the water associated with the solids. Thickening may be carried out by gravity sedimentation or by dissolved-air flotation. Flotation thickening is more amenable than gravity thickening for dewatering biological sludges because flotation thickening is not adversely affected by the decomposition gases produced by the activity of the biological sludges.

As shown in Figure 4, further treatment and sludge volume reduction may be obtained by digestion. Digestion is a biological treatment process and may be carried out aerobically or anaerobically.

Further dewatering may also be performed using vacuum filtration or centrifugation, either with or without chemicals, or using sand drying beds or lagoons.

Ultimate disposal of sludges includes disposal on land (landfill, drying for soil conditioning, land application) discharge to sea, and use of incineration and related processes.

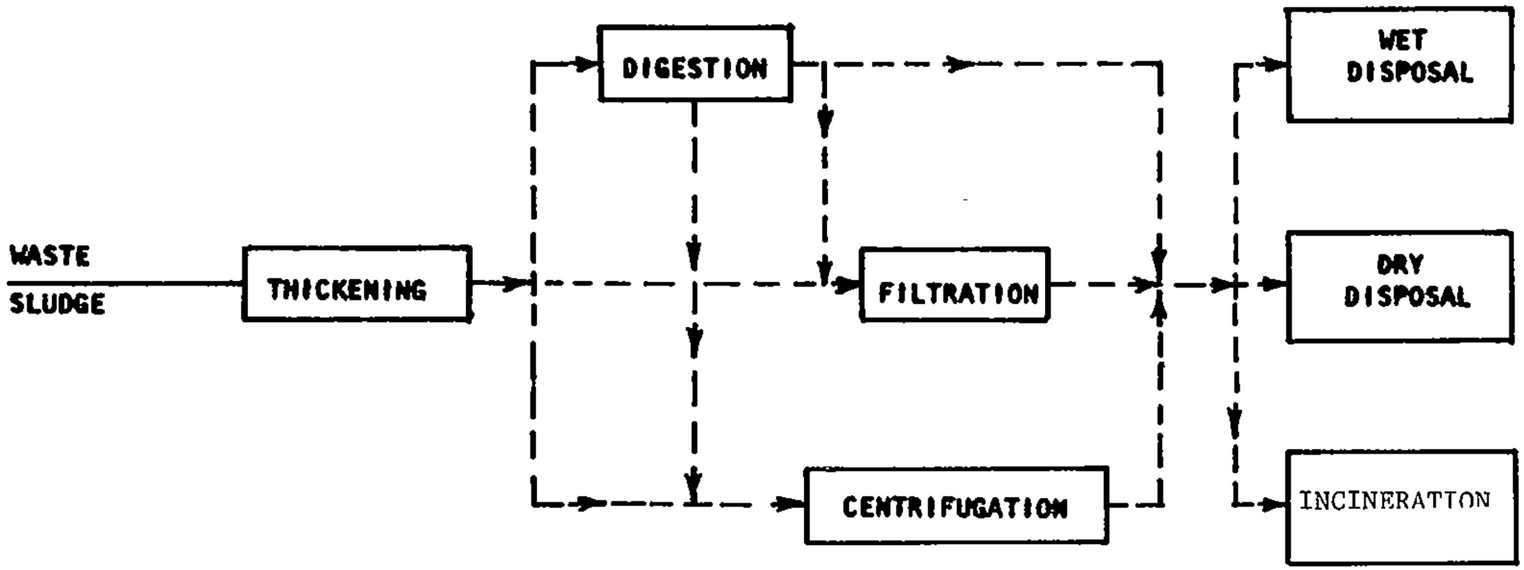


Figure 4. Schematic diagram of the various steps leading to ultimate sludge disposal.

For a particular location, the combination of the sludge handling and disposal steps to be used should be integrated in such a manner as to arrive at an optimum economical solution.

Various dry-weather design and operational parameters associated with several of the sludge handling and disposal methods were obtained from the literature (20)(22) and are summarized in Tables 9-13. Criteria for other sludge handling methods include:

1. Flotation Thickening
Solids loading of 49-59 kg/day/sq m (10-12 lb/day/sq ft) without chemicals to produce a thickened sludge concentration of 4-5% when thickening waste activated sludge.

2. Lagoons
Solids loading rates suggested for drying lagoons are 36 to 39 kg/year/cu m (2.2 to 2.4 lb/year/cu ft) of lagoon capacity.

3. Centrifugation
Pilot tests used to evaluate applications. Scale up procedures are considered proprietary and are generally not available.

These criteria, discussed above, are among those that will be used in the evaluation of the effect of CSO treatment residuals bled/pumped-back to the dry-weather sludge handling facilities.

Diurnal Dry Weather Flow and Contaminant Strengths

Another pertinent consideration to establishing the effect of bleed/pump-back is the diurnal dry-weather flow variation and contaminant concentration patterns. These patterns can have a significant effect upon the viable bleed/pump-back of CSO sludges. A typical diurnal flow and BOD pattern is shown in Figure 5. It is important to note that the diurnal pattern will vary from day to day, from week day to weekend and also from month to month.

It is apparent that the diurnal patterns developed for a dry-weather facility may be used to compare the actual loading parameters with those of the plant design values, to determine the degree of diurnal overload during dry-weather periods. It is also evident that bleed/pump-back of CSO treatment residuals will superimpose or increase the flow and contaminant loadings on the dry-weather diurnal patterns, and therefore, on the actual loadings to the dry-weather treatment facilities.

CSO Treatment Sludges Flow and Contaminant Strengths for Pump-Back

The magnitude and quality of the CSO treatment sludges to be pumped back to the dry-weather facilities is a function of the type and efficiency of CSO treatment, used. The CSO treatment methods presently being evaluated (12) may be broadly classified as physical, physical-chemical and biological. In general, it should be recognized that as treatment complexity and sophistication increase (say, from physical to biological treatment), treatment efficiency and sludge residue production also increase. The specific CSO

TABLE 9. GRAVITY THICKENER SURFACE LOADINGS AND OPERATIONAL RESULTS (22)

Type of sludge	Solids-surface loadings kg/day/sq m	($lb/day/ft^2$)	Thickened sludge solids concentration (%)
Separate sludges			
Primary	98-146	(20-30)	8-10
Modified activated	73-122	(15-25)	7-8.5
Activated	24-29	(5-6)	2.5-3
Trickling filter	39-49	(8-10)	7-9
Combined sludges			
Primary and modified activated	98-122	(20-25)	8-12
Primary and activated	29-49	(6-10)	5-8
Primary and trickling filter	49-59	(10-12)	7-9

TABLE 10. TYPICAL DESIGN CRITERIA FOR STANDARD RATE AND HIGH RATE DIGESTERS (22)

Parameter	Low rate	High rate
Solids retention time (SRT), days	30 to 60	10 to 20
Solids loading, kg VSS/cu m/day (lb VSS/cu ft/day)	0.64-1.60 (0.04 to 0.1)	2.40-6.40 (0.15 to 0.40)
Volume criteria cu m/capita (cu ft/cap.)		
Primary sludge	.056-.084 (2 to 3)	.037-.056 (1-1/3 to 2)
Primary sludge + thickening filter sludge	.112-.140 (4 to 5)	.065-.093 (1-2/3 to 3-1/3)
Primary sludge + waste activated sludge	.112-.168 (4 to 6)	.075-.112 (2-2/3 to 4)
Combined primary + waste biological		
Sludge feed concentration percent solids (dry basis)	2 to 4	4 to 6
Digester underflow concentration, percent solids (dry basis)	4 to 6	4 to 6

TABLE 11. AEROBIC DIGESTION DESIGN PARAMETERS

Parameter	Value
Solids retention time, days	10-15[a]
Solids retention time, days	15-20[b]
Volume allowance, cu m/capita	.084-.112
cu ft/capita	3-4
VSS loading, kg/cu m/day	.384-2.24
lb/cu ft/day	.024-0.14
Air requirements	
Diffuser system, cu m/min/1000 cu m	20-35[a]
cu ft/min/1000 cu ft	20-35
Diffuser system, cu m/min/1000 cu m	60[b]
cu ft/min/1000 cu ft	60
Mechanical system, kw/1000 cu m	26.6-33.3
hp/1000 cu ft	1.0-1.25
VSS, reduction, percent	35-50
Minimum DO, mg/l	1.0-2.0
Temperature, °C (°F)	>15 (>59)
Power requirement Bkw/10,000 pop. equiv.	6-7.5
BHP/10,000 pop. equiv.	8-10

[a] Excess activated sludge only.

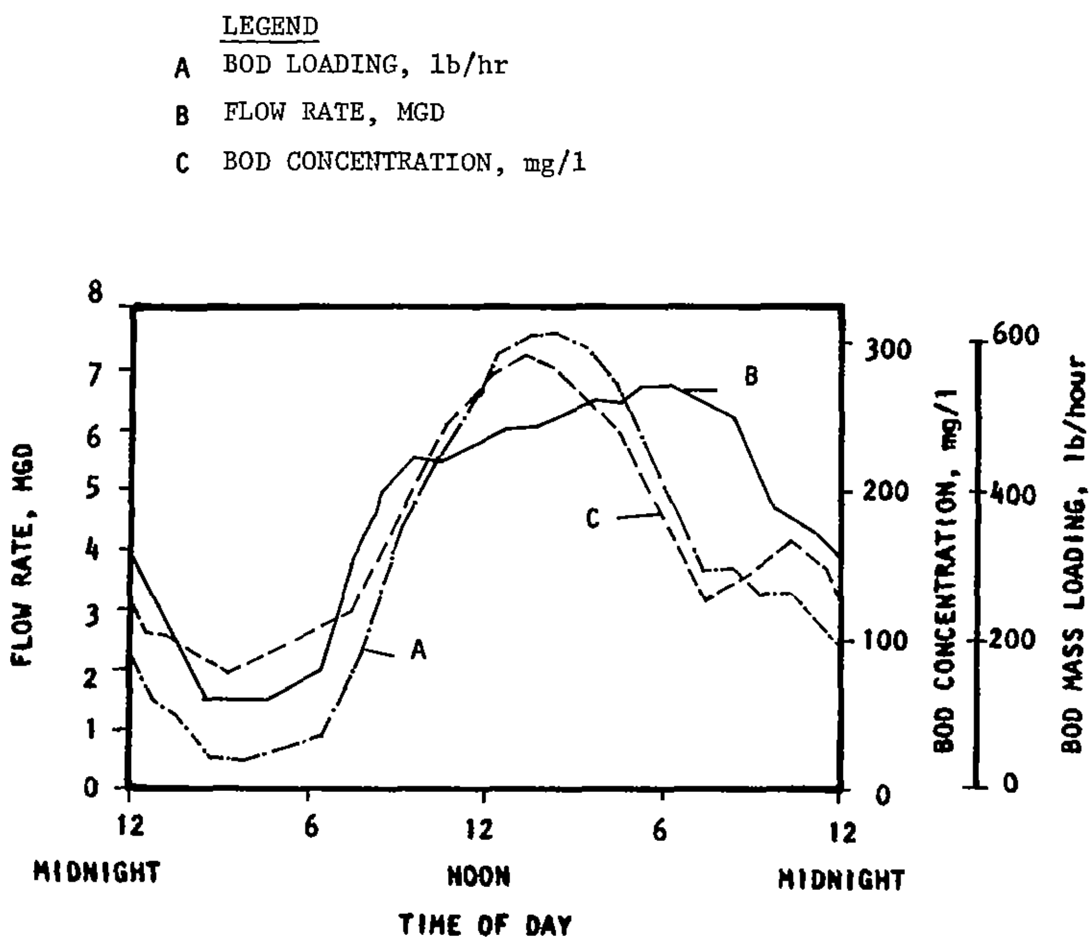
[b] Primary and excess activated sludge, or primary sludge alone.

TABLE 12. VACUUM FILTRATION DESIGN PARAMETERS AND PERFORMANCE (20)

	Type of sludge	Chemical dose rate, (%) ferric chloride	lime	Yield kg/sq m/hr (lbs/sq ft/hr)	Cake moisture (%)
1.	Raw primary	2.1	8.8	33.7 (6.9)	69.0
2.	Digested primary	3.8	12.1	35.1 (7.2)	73.0
3.	Elutriated Digested primary	3.4	0	36.6 (7.5)	69.0
4.	Raw primary + filter humus	2.6	11.0	34.6 (7.1)	75.0
5.	Raw primary + activated sludge	2.6	10.1	22.0 (4.5)	77.5
6.	Raw activated sludge	7.5	0	--	84.0
7.	Digested primary + filter humus	5.3	15.0	22.5 (4.6)	77.5
8.	Digested primary + activated sludge	5.6	18.6	19.5 (4.0)	78.5
9.	Elutriated digested primary + activated sludge:				
	(a) average w/o lime	8.4	0	18.6 (3.8)	79.0
	(b) average w/lime	2.5	6.2	18.6 (3.8)	76.2

TABLE 13. CRITERIA FOR THE DESIGN OF SANDBEDS (22)

Type of digested sludge	Area sq m/capita	(sq ft/capita)	Sludge loading dry solids kg/sq m/yr	(lb/sq ft/yr)
Primary	0.09	(1.0)	134.4	(27.5)
Primary and standard trickling filter	0.15	(1.6)	107.4	(22.0)
Primary and activated	0.28	(3.0)	73.2	(15.0)
Chemically precipitated	0.19	(2.0)	107.4	(22.0)



NOTE: MGD x 3785 = cu m/day
lb/hr x .454 = kg/hr

Figure 5. Raw wastewater and BOD variation (19).

treatment methods being considered are listed in Table 14. Estimated sludge production solids concentrations and solids disposal methods for the various CSO treatment processes are shown in Table 15. Note from Table 9, that the CSO treatment sludge quantities are based upon the quantity and quality of the raw CSO treated.

TABLE 14. CSO TREATMENT METHODS UNDER EVALUATION

1. <u>Physical Treatment</u>
   a. Storage alone
   b. Storage-sedimentation
   c. Dissolved-air flotation
   d. Screening/dissolved-air flotation
   e. Screening

2. <u>Physical-Chemical Treatment</u>
   a. Screening/dissolved-air flotation
   b. Dissolved-air flotation

3. <u>Biological Treatment</u>
   a. Contact stabilization activated sludge
   b. Trickling filters
   c. Rotating biological contactors
   d. Treatment lagoons

Furthermore, from Table 15 the major sludge disposal method used was discharge to the interceptor with ultimate disposal along with dry-weather treatment facility sludge.

The quality of the CSO treatment sludges was observed in a recently completed EPA study (12) and, in general, the conclusions drawn with regard to raw sludge characteristics were as follows:

1. The sludge volumes produced from the treatment of combined sewer overflows varied from less than 1% to 3% of the raw flow volume treated. (This is generally in agreement with Table 15).

2. The solids concentration of the sludge residuals from CSO treatment varied widely, ranging from 0.12% to 11% total suspended solids. The wide range observed is attributed to the CSO treatment method used and treatment plant operation. (This is also in general agreement with Table 15).

3. The volatile content of the sludge solids varied between 25% and 63% for the sludges obtained from the treatment types investigated. Biological treatment sludges showed the highest volatile solids fraction (about 60%), whereas that for sludges from physical/chemical treatment showed only 25 to 40% volatile fraction.

TABLE 15. SLUDGE PRODUCTION AND SOLIDS DISPOSAL METHODS FOR VARIOUS CSO TREATMENT PROCESSES[a] (9)

Process	Sludge % Solids	SS Removal (%)	Wet Sludge Volume cu m/1000 cu m	Wet Sludge Volume (cu ft/MG)	Dry Solids Volume cu m/1000 cu m	Dry Solids Volume (cu ft/MG)	Sludge Disposal Method For Demonstration Project
Sedimentation	2.5-5.0	40-75	1.92-7.40	(260-1000)	0.07-0.15	(10-20)	Return to Interceptor
Dissolved-Air Flotation	1.0-2.0	40-70	4.96-17.0	(670-2300)	0.07-0.15	(10-20)	Return to Interceptor
Bar Screens	NA[b]	---	0.01-0.03	(1-4)[c]	---	---	Landfill
Rotary Fine Screens	---	27-34	---	---	0.04-0.07	(5-10)	Return to Interceptor
Ultrafine Screens and Microstrainers	---	25-90	---	---	0.04-0.18	(5-25)	Return to Interceptor
Filtration	0.4-1.5[d]	50-90	8.14-55.5	(1100-7500)	0.07-0.18	(10-25)	Return to Interceptor
Contact Stabilization	0.5-1.5	80-95	13.3-46.6	(1800-6300)[e]	0.15-0.18	(20-25)[e]	Return to Interceptor
Trickling Filters and Rotating Biological Contactors	3.0-10.0[f]	60-90	1.48-7.40	(200-1000)	0.11-0.18	(15-25)	Return to Interceptor
Physical-Chemical	2.0-5.0	80-100	3.92-12.6	(530-1700)[g]	0.15-0.18	(20-25)[g]	Incineration/Landfill

a. Assuming 250 mg/l SS in the CSO and dry solids sp. gr. = 1.30
b. NA = not available
c. Volumes shown for screenings only, not SS
d. Low value for unsettled backwash water; high value for settled backwash water
e. Does not include waste biological solids produced in aeration tanks
f. Assuming sludge recycle
g. Does not include added chemicals

4. As might be expected, fuel value of the sludges was correlated with volatile solids content, and the biological sludges were observed to have the highest fuel values among the sludge types investigated.

5. Pesticide and PCB concentrations in the residual sludges investigated were observed to be significant. Generally, the PCB concentrations were higher than those for pp'DDD, pp'DDT and Dieldrin.

   The range of PCB and pesticide values for the various sites investigated were presented in Section IV.

6. Heavy metal (Zn, Pb, Cr, Cu, Hg and Ni) concentrations in the residual sludges were also significant, and varied widely for the sludges investigated. The range of heavy metal concentrations for the various sites investigated were also presented in Section IV.

Using the above and previous information, an attempt can be made to determine the effect of pumping back CSO treatment residuals on the operation and performance of the dry-weather plant from the standpoint of hydraulic, organic and solids overloads, effluent quality, and treatment efficiency and toxicity to treatment.

<u>Capacity Available at Dry-Weather Plant and Percent of CSO Area Contributing Sludge</u>

Other considerations must include both the treatment and sludge handling capacity available at the dry-weather plant and the percent of the total CSO area which has treatment of runoff and therefore contributes sludge for bleed/pump-back. Basic design of a new sewage treatment facility includes a "built in" safety factor (which varies with the type of process equipment) from 1.5-3 times the average loading. If the total "safety capacity" is available for handling CSO sludge or residual bleed/pump-back, this will have a significant effect on the ability of the dry-weather plant to function properly when CSO sludges are bled/pumped-back. For the purpose of the following calculations, it is assumed that the total excess capacity is available for hydraulic, solids and organic loads to the dry-weather treatment plant and sludge handling facilities.

Another variable is the total amount of CSO area which is treated by one of the state-of-the-art CSO treatment methods. If 100% of the total CSO volume is treated, this impact on the dry-weather plant is significantly greater when considering bleed/pump-back. Also, the type of CSO treatment is crucial. The sludge characteristics and volume range widely, depending upon the CSO treatment method. It is not feasible to generalize, so, for most of the calculated effects, each process has been considered individually.

<u>Basis for Bleed/Pump-Back Calculations</u>

The sections which follow address the effects of CSO sludges and dilute residuals on a composite dry-weather treatment plant and sludge handling facilities. It must be reemphasized that actual determination of the feasibility of bleed/pump-back will require the complete analytical characterization of the CSO residuals and the dry-weather treatment plant influent and sludges, a knowledge of dry-weather flow characterization and actual design constraints for each of the unit processes in the treatment plant. However, for this generalized approach it has been assumed that a secondary treatment plant followed by thickening and dewatering will be the basic dry-weather plant which would be affected by bleed/pump-back. This plant is a composite of all dry-weather treatment plants which serve the population of 36,236,000 having combined sewer systems. Also, it is assumed that all CSO area and volume in the U.S. has been treated by one of the CSO treatment methods and that these sludges will affect the composite dry-weather plant. The specific aspects for each of the four general effects are discussed individually.

EFFECT OF CSO TREATMENT RESIDUALS BLEED/PUMP-BACK ON THE OPERATION AND PERFORMANCE OF THE DRY-WEATHER TREATMENT PLANT

The bleed/pump-back of CSO sludges can have an effect on any of the design aspects of the composite treatment plant. Hydraulic, solids loading, organic loading and toxicity limits are considered individually.

1. Hydraulic Loading Considerations

It was previously brought out (Section IV) that the sewered population served by combined sewers is estimated at 36,236,000. At 473 ℓ (125 gal.) per capita per day, the dry-weather treatment plants serving that population would have a dry-weather average design flow of 17.1×10^6 cu m/day (4.53×10^9 gal./day). Most water pollution control plants are designed to function properly at flows up to some low multiple of the average dry-weather flow. Typical multiples range from 1.5 to 3.0 (9). Using this criterion, our composite national dry-weather plant might be expected to function properly up to 25.7×10^6 cu m/day to 51.4×10^6 cu m/day (6.8 to 13.6×10^{12} gal./day). Therefore, the sum of the dry-weather average design flow (17.1×10^6 cu m/day) (4.53×10^9 gal./day) plus the estimated daily CSO residual flows to be pumped back may be compared to the above two figures to determine the effect of bleed/pump-back on hydraulic overload to the dry-weather plant.

Previous discussion has estimated the annual volume of combined sewer overflow in the United States as 5.6×10^9 cu m (1.5×10^{12} gal.). Assuming 60 storm days per year (based on a 20 year average of 63 storm days per year in the Milwaukee area), the average daily combined sewer overflow is 93.4×10^6 cu m/day (24.7×10^3 MGD).

CSO treatment methods currently under evaluation have been listed in Table 14 and the sludge volumes produced by various CSO treatment processes have also been given previously (Table 1 and in Table 9). Shown in Table 16 is the effect of CSO treatment sludges bleed/pump-back on the hydraulic overload of the composite dry-weather treatment plant for the various CSO treatment processes. It should be pointed out that the data in Table 16 were calculated on the basis that the entire CSO was treated by each of the selected treatment processes alone. From

TABLE 16. EFFECT OF BLEED-BACK OF CSO TREATMENT SLUDGES ON HYDRAULIC OVERLOAD OF DWF TREATMENT PLANT (12)

CSO Treatment Process	Sludge Volume			Sludge Volume Plus Ave. DWF		Hydraulic Overload
	% of CSO Treated	million cu m/day	MGD	million cu m/day	MGD	
*Storage Alone	100	93.5	24700	110.6	29230	Yes
Storage-Sedimentation	0.9	0.83	220	18.0	4750	No
Dissolved-Air Flotation	0.6	0.57	150	17.7	4680	No
Screening/DAF	4.8	4.50	1190	21.7	5720	No
Microscreening	6.0	5.60	1480	22.7	6010	No
Contact Stabilization	3.5	3.26	860	20.4	5390	No
Trickling Filter	0.7	0.64	170	17.8	4700	No

DWF = Dry Weather Flow = 17,146,000 cu m/day (4530 MGD)(average)

Hydraulic overload determinations made by comparing sludge volume plus average DWF with design range of flows that DWF plants are expected to function properly: 26 to 51×10^6 cu m/day (6.8 to 13.6×10^3 MGD)

CSO Treated = 93.5×10^6 cu m/day (24.7×10^3 MGD) *Entire flow bled/pumped back

Table 16, it is evident that hydraulic overload would be expected only when storage alone was used to impound the entire CSO flow for bleed/pump-back. This becomes apparent when comparing the average daily CSO [90,840,000 cu m/day (24,000 MGD)] with the average daily DWF of [17,144,000 cu m/day (4,530 MGD)]. For the other CSO treatment processes investigated in Table 16, hydraulic overload would not be expected. However, the rate of residual sludge bleed/pump-back over a 24 hour period would have to be carefully controlled, with due regard to the diurnal dry-weather flow (DWF) fluctuations (See Figure 5).

The apparent hydraulic overload produced by pumping back impounded CSO from storage alone over a 24 hour period may be alleviated by spreading the bleed/pump-back period over three or more days. (Of course, any additional storms during the bleed/pump-back period may adversely affect bleed/pump-back operation). Again, the rate of bleed/pump-back would have to be carefully controlled, with due regard to the diurnal DWF flucutations.

2. Solids Loading Considerations

Untreated municipal sewage generally contains an average suspended solids content of 200 mg/l (9). For our hypothetical average DWF of 17.1×10^6 cu m/day (4,500 MGD), an average daily dry solids loading to the dry-weather plant of 3.4×10^6 kg (7.6×10^6 lbs) per day may be expected. Assuming that the range multiple of design solids that a dry-weather plant can properly handle is typically 1.5 to 3.0, the dry-weather plant may be expected to handle from 5.1×10^6 kg (11.3×10^6 lbs) per day to 10.3×10^6 kg (22.7×10^6 lbs) per day of dry solids. The above criterion will be used as one measure in evaluating the effect of solids overload resulting from pumping back CSO treatment residuals to the dry-weather plant.

Shown in Table 17 is the effect of bleed/pump-back of CSO treatment sludges on the solids overload of the composite dry-weather treatment plant for the various CSO treatment processes investigated. Again, it should be pointed out that the data in Table 17 were calculated on the basis that the entire CSO was treated by each of the selected treatment processes alone. The solids removal efficiencies in Table 17 for the CSO treatment processes investigated are reasonably in the range of those expected as indicated in the literature (9).

From Table 17, it is evident that a marked solids overload may be expected by pumping back CSO treatment sludges to the DWF treatment plant over a 24 hour period. In fact, the minimum solids overload varies from about 150% to about 400%. The magnitude of the solids overload varies directly with the solids removal efficiency of the CSO treatment processes in question. The appreciable solids overload exerted on the DWF treatment plant by pumping back CSO treatment residuals may be expected to additionally adversely affect organic loading, effluent quality and treatment plant efficiency,

TABLE 17. EFFECT OF BLEED/PUMP-BACK OF CSO TREATMENT SLUDGES ON SOLIDS OVERLOAD OF DWF TREATMENT PLANT (12)

CSO Treatment Process	Sludge Pumped Back					CSO + DWF Solids		Solids Overload
	million cu m/day	MGD	Percent Solids	Dry Solids $kg/day \times 10^{-6}$	*Dry Solids $lb/day \times 10^{-6}$	$kg/day \times 10^{-6}$	$lb/day \times 10^{-6}$	
Storage Alone	93.5	24700	0 041	38.4	84 5	41.8	92.1	Yes
Storage-Sedimentation	0.83	220	1.74	14.5	31.9	17.9	39.5	Yes
Dissolved-Air Flotation	0.57	150	2.75	15.6	34 4	19.1	42.0	Yes
Screening/DAF	4.50	1190	0.84	37.9	83 4	41.3	91.0	Yes
Microscreening	5.60	1480	0.70	39.2	86.4	42.7	94 0	Yes
Contact Stabilization	3.26	860	1.00	32.6	71.7	36.0	79.3	Yes
Trickling Filter	0.64	170	3.20	20.6	45 4	24.1	53.0	Yes

CSO Treated = 93.5×10^6 cu m/day (24,700 MGD)

Solids overload determination made by comparing sum of CSO + DWF solids with the design range of solids that DWF plants are expected to function properly:

5.1×10^6 to 10.3×10^6 kg/day (11.3×10^6 to 22.7×10^6 lb/day)

Available Capacity = 5.2 million kg/day

*Descrepancies in dry solids are due to inaccuracies in pilot plant experimental data

That substantial amounts of solids are transported to the dry-weather plants during wet weather conditions is substantiated by significant data available from the literature. For example, presented in Table 18 are data showing the quantities of grit collected during dry and wet weather periods for various United States installations. The data in Table 18 show that the grit volume ratio of wet to dry weather was appreciable, with the highest ratio at 1800 times the average dry-weather grit production.

The literature (9) also indicates that often the stormwater solids contribute a large increase in fine solids (silt) which is too fine to be removed in the grit chambers and results in overloading the primary sedimentation basins. The magnitude of the solids overload on the primary tanks may be estimated. For example, in Table 8 are shown the allowable range in hydraulic loading for primary tanks (16.3-65.1 ℓ/min/sq m) (0.4-1.6 gal./min/sq ft) and the allowable solids loading range for those basins (2.4-9.8 kg/day/sq m) (0.5-2.0 lb/day/sq ft). Assuming a dry weather influent solids concentration of 100 mg/l at the higher overflow rate (65.1 ℓ/min/sq m) (1.6 gpm/sq ft), the addition of CSO treatment residual solids may result in increasing the primary tank influent solids concentration to an estimated 150 mg/l to 400 mg/l. This would be expected to result in grossly overloading (14.2 to 37.6 kg/day/sq m) (2.9 to 7.7 lb/day/sq ft) the primary basins and detrimentally affecting primary effluent quality and treatment efficiency. Moreover, the high primary overflow rate (65.1 ℓ/min/sq m (1.6 gpm/sq ft) would result in grossly hydraulically overloading the activated sludge final tanks and to adversely affect final effluent quality and overall treatment efficiency.

Again, it may be apparent that the solids overloads to the dry-weather plant described above may be alleviated by storing the CSO treatment sludges and spreading the bleed/pump-back period over two to four days or more. Of course, any additional storms during the bleed/pump-back period may adversely affect the bleed/pump-back operation. Additionally, the rate of bleed/pump-back would have to be carefully controlled, with due regard to the diurnal DWF fluctuations.

3. Organic Loading Considerations

Untreated municipal sewage contains about 200 mg/l BOD (9) (19). Shown in Table 19 are the BOD characteristics observed for various CSO treatment residual sludges (12). The BOD concentrations of the sludges investigated varied widely, increasing with increasing sludge concentration. The BOD values shown in Table 19 were those associated with the solids contents of the corresponding sludge presented in Table 17.

One of the criteria to be used in evaluating organic overload is associated with the activated sludge portion of the treatment. Design organic loading DWF parameters for the aeration tank are shown in Table 8, and the organic loading range indicated is 0.35 to 0.5 kg (lb) BOD/day per kg (lb) MLSS. In addition, removals of BOD from DWF primary

TABLE 18. VARIATION IN QUANTITIES OF GRIT REMOVED DURING WET WEATHER AND PERIODS OF AVERAGE FLOW (17)

Municipality	Grit removed $cu\ m/10^6\ cu\ m$ (cu ft/MG) average day		maximum(wet) day		Ratio between maximum and average
Baltimore, MD	40	(5.4)	109	(14.8)	2.7
Battle Creek, MI	139	(18.8)	1258	(170.0)	9.0
Beacon, NY	23	(3.1)	138	(18.7)	6.0
Birmingham, AL	6	(0.8)	6	(0.8)	1.0
Cleveland, Ohio (East)	2	(0.3)	3995	(540.0)	1,800.0
Fort Dodge, IA	24	(3.2)	24	(3.2)	1.0
Green Bay, WI	52	(7.0)	56	(7.6)	1.1
Jeannette, PA	42	(5.7)	60	(8.1)	1.4
Kokomo, IN	10	(1.3)	74	(10.0)	7.7
La Crosse, WI	20	(2.7)	42	(5.7)	2.1
Muskegon, MI	10	(1.3)	60	(8.1)	6.2
Rockford, IL	50	(6.8)	119	(16.0)	2.3
Springfield, OH	16	(2.2)	48	(6.5)	2.9
Virginia Beach, VA	18	(2.4)	56	(7.5)	3.1

TABLE 19. ORGANIC CHARACTERISTICS (BOD) OF CSO TREATMENT RESIDUAL SLUDGES (9) (12)

CSO Treatment Process	BOD mg/l	Volume Pumped Back million cu m/day	Volume Pumped Back MGD	BOD Pumped Back kg/dayx10^{-6}	BOD Pumped Back lb/dayx10^{-6}	BOD Removed By Primary Treatment kg/dayx10^{-6}	BOD Removed By Primary Treatment lb/dayx10^{-6}	BOD To Activated Sludge kg/dayx10^{-6}	BOD To Activated Sludge lb/dayx10^{-6}	Number Of Days Required For Pump Back
Storage Alone	115	93 5	24700	10 8	23.7	3 8	8.3	7.0	15 4	11.9
Storage-Sedimentation	2200	0.83	220	1 8	4.0	0 6	1 4	1.2	2 6	2.0
Dissolved-Air Flotation	1000	0.57	150	0.6	1 3	0.2	0 5	0 4	0.9	0.6
Screening/DAF	1100	3.18	840	3.5	7.7	1.2	2 7	2 3	5.0	3.8
Contact Stabilization	1700	3.26	860	5 5	12.2	2.0	4.3	3 6	7.9	6 1
Trickling Filter	11200	0 64	170	7.2	15 9	2 5	5 6	4 7	10.3	7.9

Assumed 35% BOD removal by primary treatment at 40.8 cu m/day/sq m (1000 gpd/sq ft)

Number of days are based on DWF organic loading of 0.35 kg BOD/day/kg MLSS with possibility of increasing the organic loading to a maximum of 0.5 kg BOD/day/kg MLSS or an increase of 588,076 kg BOD/day (1,295,321 lb BOD/day) sedimentation is about 35% at an overflow rates of 40.8 cu m/day sq m (1000 gal./day/sq ft) (14)(15). Suspended solids and BOD removals drop drastically at primary tank overflow rates greater than 40.8 cu m/day/sq m (1000 gal./day/sq ft). For example, at an overflow rate of 19.8 cu m/day/sq m (2300 gal./day/sq ft), BOD removal decreases to about 20% (15) and suspended solids removal decreases to about 37% (14).

From previous discussion, it has been indicated that bleed/pump-back of CSO treatment sludges to the dry-weather plant over a 24 hour period will result in hydraulic and/or suspended solids overload. Furthermore, it was indicated that the overloads to the dry-weather plant may be alleviated by spreading the bleed/pump-back period over several days or more. Moreover, it is indicated that the bleed/pump-back period would be further extended because the primary tank operation is critical with regard to BOD and suspended solids removal and the resultant organic load to the secondary treatment system. Optimum operation of the primary tanks is an overflow rate of 40.8 cu m/day/sq m (1000 gal./day/sq ft) in order to maximize BOD and suspended solids removal. This overflow rate is appreciably less than the maximum normally allowed for DWF operation, [93.6 cu m/day/sq m (2300 gal./day/sq ft] (See Table 8).

Untreated municipal sewage generally contains an average BOD content of 200 mg/l and an average suspended solids content of 200 mg/l (9). For our hypothetical average DWF of 17.1×10^6 cu m/day (4,500 MGD), an average daily BOD and suspended solids loading to the dry-weather plant of 3.4×10^6 kg (7.6×10^6 lbs) per day each may be expected. Operating the primary treatment plant at a design overflow rate of 40.8 cu m/day/sq m (1000 gal./day/sq ft)(18), BOD removals of 35% (1.2×10^6 kg/day) (2.6×10^6 lb/day) may be expected and suspended solids removals of 60% 2.1×10^6 kg/day (4.5×10^6 lb/day) would be anticipated. Therefore, the organic (BOD) loading on the secondary activated sludge treatment system during dry-weather flow would be 2.2×10^6 kg/day (4.9×10^6 lb/day), and the corresponding solids loading to the secondary treatment plant would be 1.4×10^6 kb/day (3.0×10^6 lb/day) during dry-weather periods. From Table 8, the allowable organic loading range on the activated sludge system is 0.35-0.50 kg(lb) BOD/day/kg(lb) MLSS. Assuming our activated sludge plant is operating at the lowest end of the organic loading scale (0.35 kg(lb) BOD/day/kg(lb) MLSS) or 600,000 kg (1.3×10^6) lb) BOD/day may be added in the form of bled/pumped-back CSO treatment residuals. Of course, if the activated sludge plant is operating consistently at the upper end of the organic loading scale (0.5 kg(lb) BOD/day/kg(lb) MLSS), then no additional CSO treatment residuals can be bled/pumped-back to the DWF plant without organically overloading it. Also, if the DWF secondary plant is operating at somewhere in between the allowable organic range, then less additional BOD load than was previously indicated can be pumped back to the DWF plant.

Inasmuch as the rate of flow of CSO sludges bleed/pump-back is limited to the extent that the primary tank operation does not exceed an overflow rate of 40.8 cu m/day/sq m (1000 gal./day/sq ft), it becomes apparent from an examination of Figure 5 (DWF diurnal variations) that bleed/pump-back will be intermittent and restricted to low DWF periods during the day.

The above described constraints all tend to restrict the rate of bleed/pump-back flow downward to the extent that the total time period for pumping back the total CSO sludges volume is extended, which is an unfavorable trend from the standpoint of handling the effects of a succeeding series of storms. Shown in Table 19 are the number of days required for bleed/pump-back of the CSO treatment sludges from one average storm from an organic loading standpoint, when the DWF plant is operating at a low organic loading (0.35 kg(lb) BOD/day/kg(lb) MLSS). The number of days required to bleed/pump-back the CSO treatment residuals increases proportionately from those in Table 19, as the DWF organic loading increases from 0.35 to 0.5 kg(lb) BOD/day/kg(lb) MLSS. Also, as mentioned previously, DWF plants having organic loadings at the maximum of 0.5 kg(lb) BOD/day/kg(lb) MLSS may not be able to accept CSO treatment residuals if they are consistently heavily loaded.

From Table 19, it may be seen that four of the six CSO treatment methods investigated would require about four or more days for bleed/pump-back of a single storm's treatment sludges to the DWF plant when the dry-weather plant is operating at a low organic loading level. The time required for bleed/pump-back would be expected to increase as the dry-weather organic loading level increased.

From Table 19, it may also be seen that two of the six CSO treatment methods investigated would require two or less days for bleed/pump-back of a single storm's treatment sludges to the DWF plant when the dry-weather plant is operating at a low organic loading level. Again, the time required for bleed/pump-back would be expected to increase as the dry-weather organic loading level increased. Furthermore, it should be pointed out that the two CSO treatment methods involved here, sedimentation and dissolved-air flotation, were relatively low efficiency solids removal processes (about 40% suspended solids removal, (See Table 17)). Any increase in solids removal efficiency for these treatment processes would result in an increase in the bleed/pump-back period. Moreover, the CSO treatment processes in question are primary treatment methods and the treated effluents produced may require further treatment which would produce additional sludge for bleed/pump-back, thereby increasing the total bleed/pump-back time period.

Concurrent with the organic loading considerations, described above and under the operating conditions listed in Table 19, is the solids loading imposed on the secondary treatment plant and its concurrent effect on that operation. For our hypothetical DWF plant treating 17.1×10^6 cu m/day (4,530 MGD), it was previously calculated that the suspended solids loading to the dry-weather plant was 3.4×10^6 kg/day (7.6×10^6 lb/day). Operating the primary treatment plant at an overflow rate of 40.8 cu m/day/sq m (1000 gal./day-sq ft), suspended solids removals of 60% 2.1×10^6 kg/day (4.5×10^6 lb/day) may be expected, and the suspended solids loading to the secondary treatment plant would be 1.4×10^6 kg/day

3.0×10^6 lb/day) during dry-weather periods. From Table 7, the allowable solids loading on final clarifiers is 98 to 146 kg/day/sq m (20-30 lb/day/sq ft). Assuming our final clarifiers during dry-weather are operating at the lowest end of the solids loading scale 98 kg/day/sq m (20 lb/day/sq ft), then an additional solids load (up to 146 kg/day/sq m) (30 lb/day/sq ft) of 0.7×10^6 kg/day (1.5×10^6 lb/day) may be added in the form of pumped back CSO treatment residuals. Shown in Table 20 is the solids loading effect on the secondary treatment plant when pumping back CSO residuals at a rate which will prevent organic overload (See Table 13). From Table 20 it may be seen that under the operating conditions previously described, a gross solids overload is effected, and this indicates that solids overload is the limiting factor affecting the bleed/pump-back time period. It is indicated, therefore, that the bleed/pump-back time periods shown in Table 19 should be appreciably increased, which makes the concept of CSO residuals bleed/pump-back to the dry-weather plant more impractical from the standpoint of successfully handling the effects of succeeding storms in series.

4. Toxicity to Treatment

Some possible toxic substances in CSO treatment sludges for which data is available include heavy metals (zinc, lead, copper, nickel, chromium and mercury), PCB and pesticides (pp'DDD, pp'DDT and dieldrin). Heavy metal, PCB and pesticide concentrations in CSO treatment sludges were found to be significant, and the ranges of concentrations observed have been previously reported herein.

Heavy Metals - Domestic wastewater generally contains low concentrations of metals. The high concentrations of metals in wastewater are normally caused by the discharge of industrial wastes (such as metal finishing shops, plating wastes, etc.). Therefore, the metals content for municipal treatment plants may range from traces to 20 mg/l or more (23). During wet weather, street runoff may produce high concentrations of certain metals in combined sewers, on the order of 10 to 100 times and more than those normally present in domestic wastewater as shown in Table 21 (23,24).

Pertinent to this discussion is the determination of any toxic effect of heavy metals to treatment in the dry-weather plant operation caused by pumping back of CSO treatment sludges. The toxic effect, if any, would manifest itself in the secondary treatment portion of the dry-weather plant. Shown in Table 22 are criteria which are to be used in arriving at such a determination. Moreover, the literature indicates that mercury dosages of 5 mg/l or higher definitely inhibit aerobic biological processes (25). The inhibitory effect of lead on biological treatment was not uncovered in the literature, however, it was observed that primary sewage treatment removes "most" of the lead in sewage (21).

Presented in Table 23 are the heavy metal concentrations found in sanitary sewage (from Table 21) (24) and in the sludges from various CSO treatment processes (12). It may be recalled that previous discussion

TABLE 20. CONCURRENT SOLIDS LOADING ON SECONDARY TREATMENT PLANT UNDER THE OPERATING CONDITIONS DESCRIBED IN TABLE 13

CSO Treatment Process	Solids Pumped Back		Solids Removed By Primary Treatment		Bleed/ Pump- Back Period (days)	Solids To Activated Sludge		Secondary Solids Overload
	$kg/day \times 10^{-6}$	$lb/day \times 10^{-6}$	$kg/day \times 10^{-6}$	$lb/day \times 10^{-6}$		$kg/day \times 10^{-6}$	$lb/day \times 10^{-6}$	
Storage Alone	38.4	84.5	22.7	50.1	11.9	1 3	2.9	Yes
Storage-Sedimentation	14.5	31.9	8.7	19.1	2.0	2.9	6.4	Yes
Dissolved-Air Flotation	15.6	34.4	9.4	20.6	0 6	10 4	23.0	Yes
Screening/DAF	37.9	83.4	22.7	50.0	3.8	4.0	8.8	Yes
Contact Stabilization	32.6	71.7	19.5	43.0	6.1	2.1	4.7	Yes
Trickling Filter	20.6	45.4	12.3	27.2	7.9	1.0	2 3	Yes

Bleed/Pump-Back solids were obtained from Table 11.

Assumed 60% SS removal by primary treatment at 40.8 cu m/day/sq m (1000 gpd/sq ft)

Solids overload was established when the CSO solids to the activated sludge system exceeded 686,088 kg/day (1,511,208 lb/day)

TABLE 21. METAL LOADING FROM ROAD SURFACE RUNOFF COMPARED TO NORMAL SANITARY SEWAGE FLOW (24)

Metal	Road runoff (mg/l)	Sanitary sewage (mg/l)	Runoff: sewage (ratio)
Pb	6.2	0.03	210
Cd	0.012	0.00075	16
Ni	0.10	0.01	10
Cu	0.37	0.04	9
Zn	1.4	0.20	7
Fe	83	13	6
Mn	1.6	2.3	0.7
Cr	0.80	2.8	0.3

Note: From a 0.25 cm rain (0.1 in.)

TABLE 22. EFFECTS OF HEAVY METALS ON BIOLOGICAL TREATMENT PROCESSES (26)

Metal	5-10% reduction in aerobic treatment efficiency	4-hr slug dose, causing reduction in COD removal	Highest allowable dose for satisfactory anaerobic sludge digestion
Cr	10 mg/l	>500 mg/l	>50 mg/l
Cu	1	75	5
Ni	1-2.5	50-200	>10
Zn	5-10	160	10

has indicated that bleed/pump-back of CSO treatment sludges over a 24 hour period would result in hydraulic, solids and organic overload of the dry-weather treatment plant facility. Moreover, it was further indicated that to prevent overload conditions, CSO treatment sludges would have to be stored and pumped back to the dry-weather plant over extended periods of time. For example, for efficient CSO treatment processes (storage alone, contact stabilization, screening/DAF, etc.) bleed/pump-back periods appreciably greater than 4 to 12 days have been indicated.

However, for purposes of this discussion in determining the toxic effect of CSO treatment sludges' heavy metals on dry-weather secondary treatment, a bleed/pump-back period of 24 hours will be assumed. If the combined heavy metal concentrations obtained under this condition are found not to be toxic to secondary treatment during dry weather conditions, then toxic conditions may not be expected over the more extended bleed-back periods.

Using our hypothetical average dry weather flow of 17.1×10^6 cu m/day (4,500 MGD), the daily CSO treatment sludge volumes expected (Table 5) and the appropriate heavy metal concentrations in the two flows (Table 23), the average heavy metal concentration of the blend of dry weather and CSO residual flows at the dry weather plant influent may be determined. The results of these calculations are shown in Table 24 on the basis that the entire CSO was treated by each of the selected CSO treatment processes alone. Also presented in Table 24 are the heavy metal concentrations contributing detrimentally to the efficiency of aerobic biological treatment. Noted in Table 24 are those values which significantly exceed the toxicity causing concentrations listed at the bottom of Table 24. It is indicated that copper and zinc in contact stabilization, storage alone and trickling filter treatment residuals warrant further discussion regarding toxicity to treatment. The values shown in Table 24 are the heavy metal concentrations at the influent to the dry weather plant. Assuming the heavy metals are predominantly of a particulate nature, a 60% reduction may be expected by primary treatment. Therefore, the primary effluent to secondary treatment will contain heavy metal concentrations of 40% of the values presented in Table 24. The primary effluent heavy metals contents so calculated will all be below the critical concentrations detrimental to secondary treatment efficiency. The general conclusion may be drawn from the above discussion that pumping back of CSO treatment sludges to the dry-weather plant will not result in heavy metal toxicity to secondary treatment. However, this is a preliminary and elementary study and the subject requires further attention.

PCB (12)(27) - This chemical, which has been contaminating fish, has been in common use since 1929. It is used in many products ranging from soaps to electrical transformers. In 1972, Monsanto Industrial Chemical Co., the only PCB manufacturer in the United States, stopped selling it except for use in closed electrical items such as transformers and capacitors. However, it still continues to get into waters from past usage and spills.

PCB is suspected of causing reproductive failure in fish, birds, and

TABLE 23. COMPARISON OF HEAVY METAL CONCENTRATION IN SANITARY SEWAGE AND VARIOUS CSO TREATMENT SLUDGES

	Zinc mg/l	Lead mg/l	Copper mg/l	Nickel mg/l	Chromium mg/l	Mercury mg/l
Sanitary Sewage	0.20	0.03	0.04	0.01	2.80	---
CSO Treatment Process						
Storage Alone	0.6	0.7	1.5	0.1	0.05	0.001
Storage-Sedimentation	15.2	29.0	8.4	2.5	4.4	0.05
Dissolved-Air Flotation	19.4	43.3	10.0	2.3	45.6	0.11
Screening/DAF	13.8	8.6	4.1	1.8	1.8	0.02
Microscreening	8.3	17.1	1.4	2.0	0.4	0.01
Contact Stabilization	71.5	5.3	14.5	5.3	17.3	0.03
Trickling Filter	41.7	11.4	32.8	25.2	79.5	---

TABLE 24. EVALUATION OF THE POSSIBLE TOXIC EFFECT OF HEAVY METALS ON DRY WEATHER TREATMENT DUE TO BLEED/PUMP-BACK OF CSO TREATMENT SLUDGES

CSO Treatment process	Concentration (mg/l after blending CSO sludge with dry weather flow)				
	Zinc	Copper	Nickel	Chromium	Mercury
Storage	0.5	1.3*	0.1	0.5	.001
Storage-sedimentation	0.9	0.4	0.1	2.9	.002
Dissolved-air flotation	0.8	0.4	0.1	4.2	.0001
Screening/DAF	3.0	0.9	0.4	2.6	.004
Microscreening	2.2	0.4	0.5	2.2	.002
Contact stabilization	11.5*	2.3*	0.9	5.1	.005
Trickling filter	1.7	1.2*	0.9	5.6	--

Concentrations of heavy metals causing a 5-10% reduction in aerobic treatment efficiency:

Zinc	5-10 mg/l
Copper	1 mg/l
Nickel	1-2.5 mg/l
Chromium	10 mg/l

* Values that are within or above given concentrations for causing a reduction in efficiency.

mammals. In human beings, it is suspected of causing cancer, skin discolorations and liver disorders. It is also suspected of affecting a person's recovery from other illnesses.

The literature (27) indicates that PCB is present in municipal sewage in amounts varying from 0.17 to 140 µg/l. Moreover, it is further indicated that municipal treatment plants are capable of removing more than 70% of the incoming PCB. However, over half the municipal treatment plants studied (27) had effluent concentrations ranging from 0.1 to 0.5 µg/l PCB, and about 20% of the plants studied had effluent concentrations greater than 1.0 µg/l PCB.

The mechanism of PCB removal in treatment plants appears to be adsorption on the solids with subsequent sedimentation clarification of the solids. This is evident from data collected (27) which show comparatively high concentrations of PCB in primary settling sludges (50 mg/l) and digester sludges (22 mg/l). In contrast, the CSO treatment sludges may be expected to contain PCB concentrations varying from 0.008 mg/l to 0.118 mg/l (27) which are several magnitudes lower than those concentrations reported from municipal dry weather sludges.

From the above discussion, it appears that the PCB content of the CSO treatment sludges will not cause toxicity to dry weather treatment if the CSO sludges are pumped back to the dry weather plant, all other things being equal. However, bleed/pump-back of CSO treatment sludges to the dry weather plant can increase the effluent PCB concentration and mass PCB transport to receiving waters if the dry weather facility becomes overtaxed.

<u>Pesticides (28)(29)</u> - Pesticides may be described as natural and synthetic materials used to control unwanted or noxious animals and plants. They may be conveniently classified according to their usage, such as fungicides, herbicides, insecticides, fumigants and rodenticides. The widespread presence of pesticides in the environment has caused much public and private concern because of their potential for upsetting ecological balances. Their dispersal in drainage systems and possible eventual accumulation in estuaries makes our coastal fisheries (for example, oysters, shrimp, crab and menhaden) especially vulnerable to their toxic effects. Laboratory tests show that these economically important animals are especially sensitive to the toxic effects of low levels of pesticides. For example, oysters will exist in the presence of DDT at levels as high as 0.1 mg/l in the environment, but at levels 1000 times less (0.1 µg/l), oyster growth or production would be only 20% of normal, shrimp populations would suffer a 20% mortality, and menhaden would suffer a disastrous mortality. Some insecticides are toxic enough to kill 50% or more of shrimp populations after 48 hours exposure to concentrations of only 30 to 50 nanograms per liter of the compounds.

Pesticides may be classified by their chemical affinities, their degree of toxicity and their degree of persistence. Pesticides which are acutely toxic to shrimp at low concentration levels (µg/l) include the organochlorine and organophosphorous insecticides. The organochlorines include the well-known DDT and aldrintoxaphene group, and typically, they are persistent compounds. The organophosphorous compounds include parathion, and typically, they hydrolyze or break down into less toxic products much more readily than the organochlorine compounds. Therefore, the organophosphorous compounds are usually preferable as control agents because of their relatively short life.

The pesticide content in municipal sewage was not uncovered in the literature. However, the concentrations of selected pesticides found in CSO treatment sludges are shown in Table 25. From Table 25, the pesticide content observed varied from non-detectable to significant. Note in Table 25, that the pesticides investigated were organochlorine insecticides.

Pumping back CSO treatment sludges to our hypothetical dry-weather plant over a 24 hour period will result in influent pesticide concentrations of the combined flow as shown in Table 26. The values shown in Table 26 were calculated using an average dry-weather flow of 17.1×10^6 cu m/day (4,500 MGD) (assuming no pesticide content), the daily CSO treatment residual volumes expected (Table 17) and the pesticide concentrations in the CSO treatment sludge volumes (Table 25). The results shown in Table 26 are on the basis that the entire CSO was treated by each of the selected CSO treatment processes alone.

The 48 hour TL_m (shrimp) for DDT and dieldrin are 0.6 µg/l and 0.3 µg/l, respectively (28). Comparing these values with those in Table 26 indicates that the corresponding values for the combined influent before treatment are well below the limit.

Also not covered in the literature was the extent of pesticide removal in municipal sewage treatment plants. However, it was indicated that pesticides are subject to a number of degrading actions, including volatilization, decomposition by ultraviolet light and other radiation, chemical degradation, microbial degradation and sorption by solids. Microbial degradation and sorption on solids appears to be the mechanism by which pesticides would be removed in a sewage treatment plant. The pesticide levels shown in Table 26 would not appear to be toxic to sewage treatment.

5. Effluent Quality and Treatment Efficiency

One of the most important criterion in evaluating the alternative of the bleed/pump-back of CSO treatment residuals to the dry weather plant is its effect upon treatment efficiency and effluent quality. Previous discussion has dwelled upon the effect of CSO residuals bleed/pump-back on the dry-weather treatment plant with regard to such criteria as hydraulic overload, solids overload, organic overload and toxicity to treatment. The effects on these criteria were found to be interrelated and to affect treatment efficiency and effluent quality for each treatment process element as well as for the overall treatment plant itself. It was observed that inasmuch as the treatment processes comprising the

TABLE 25. CONCENTRATION OF SELECTED PESTICIDES IN CSO TREATMENT SLUDGES (12)

CSO Treatment process	pp'DDD µg/l	pp'DDT µg/l	Dieldrin µg/l
Storage alone	ND	0.03	0.006
Storage-sedimentation	ND	3.00	0.67
Dissolved-air flotation	0.79	2.63	5.25
Screening/DAF	1.90	ND	0.14
Microscreening	ND	ND	ND
Contact stabilization	0.93	ND	0.88
Trickling filter	ND	ND	ND

ND = non-detectable

TABLE 26. EFFECT OF BLEED/PUMP-BACK OF CSO TREATMENT SLUDGES ON DRY WEATHER PLANT INFLUENT PESTICIDE CONCENTRATIONS

CSO Treatment process	Concentration (µg/l after blending CSO sludge with dry weather flow)		
	pp'DDD	pp'DDT	Dieldrin
Storage alone	ND	0.03	0.005
Storage-sedimentation	ND	0.14	0.04
Dissolved-air flotation	0.03	0.08	0.17
Screening/DAF	0.4	ND	0.03
Microscreening	ND	ND	ND
Contact stabilization	0.15	ND	0.14
Trickling filter	ND	ND	ND

ND = non-detectable

dry-weather plant are in series, any significant effect on any upstream treatment process will have significant effect on the performance of one or more of the downstream treatment processes. The discussion below summarizes the effect of CSO residuals bleed/pump-back on dry weather treatment plant treatment efficiency and effluent quality.

The effect of bleed/pump-back on various aspects of treatment plant loading have been discussed in detail. It is apparent that the rate of bleed/pump-back of CSO sludges to the dry-weather treatment plant is critical and appreciably affects the subsequent operation of the plant and the plant performance achieved.

Ideally, bleed/pump-back of the CSO treatment residuals over a 24 hour period would be most favorable from the standpoint of permitting the handling of subsequent CSO events in series. Previous discussion indicated, however, that discharge of the expected quantities of CSO treatment residuals to the dry weather plant over a 24 hour period would grossly overload the dry-weather treatment plant either hydraulically, solids-wise and/or organically, resulting in appreciably decreasing the treatment efficiency and intolerably (above allowable limits, see Table 8 and EPA regulations) deteriorating the plant effluent quality with regard to suspended solids, BOD, heavy metals, PCB and/or pesticides.

Inasmuch as a CSO residuals bleed/pump-back rate over a 24 hour period is impractical, the overload and unfavorable operating conditions caused thereby may be alleviated by storing the CSO treatment residuals and extending the bleed/pump-back period (reducing the bleed/pump-back rate) as required. Table 27 includes a summary of the limiting time periods for bleed/pump-back which can occur without overloading the capacity of the dry-weather treatment plant.

TABLE 27. LIMITING FACTORS IN DAYS FOR BLEED/PUMP-BACK

Treatment process	Days for bleed/pump-back				
	Hydraulic	Solids (Prim.)	Organic	Final Clarifier	Toxic
Storage	2.1	7.4	11.9	22.3	<1
Sedimentation	<1	2.8	2.0	9.5	<1
Dissolved Air Flotation	<1	3.0	0.6	9.1	<1
Screening/Dissolved Air Flotation	<1	7.3	3.8	22.1	<1
Microscreening	<1	7.5	-	-	-
Contact Stabilization	<1	6.3	6.1	19.0	<1
Trickling Filter	<1	4.0	7.9	12.0	<1

As can be seen, the most limiting aspect of bleed/pump-back of CSO sludges to the dry-weather treatment plant occurs with regard to the final clarifier solids loading. Storage and bleed/pump-back of sludge over periods of 8-22 days has several disadvantages. A major disadvantage of this alternative is that the capability of handling succeeding CSO treatment residual events is reduced. In fact, the longer the extended bleed/pump-back period, the more unfavorable this alternative becomes. Another disadvantage of any bleed/pump-back alternative is the necessity for carefully controlling bleed/pump-back (flow rate and constituent strength), with due regard for the diurnal DWF fluctuations (flow rate and constituent strength) to insure that peak treatment plant design operating conditions are not exceeded.

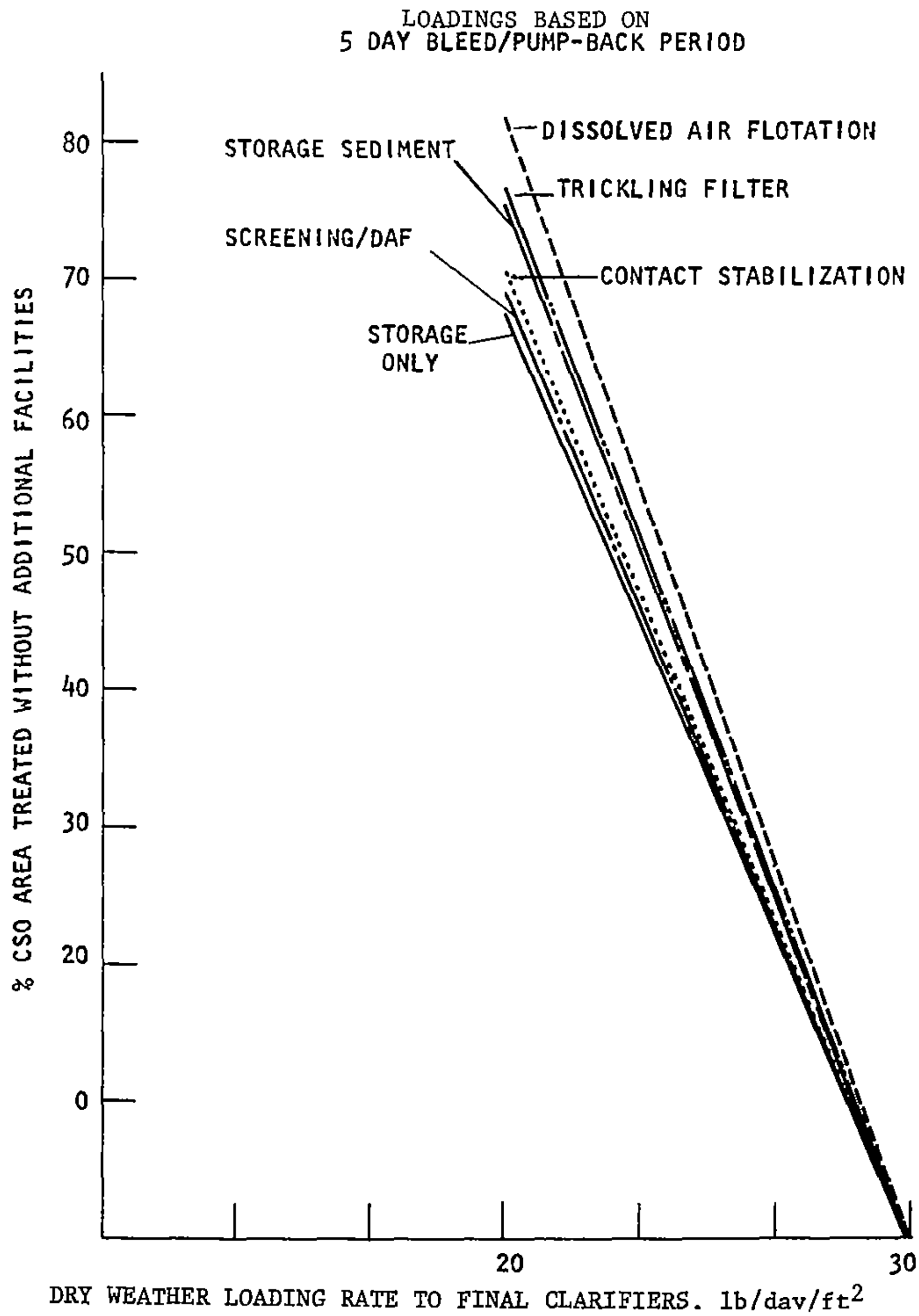
The final disadvantage is that the treatment efficiency and effluent quality would be lower than when CSO sludges are not bled/pumped-back. In order to minimize the bleed/pump-back period and the associated storage volumes required, it is assumed that the bleed/pump-back rate will be established so the dry-weather treatment plant will operate at the peak design operating conditions. It is felt that under this severe loading, the effluent discharge limitations (30 mg/l suspended solids and 30 mg/l BOD) would be exceeded. If the suspended solids loading is higher, then the effluent quality would range in the upper portion of the performance expectation and may reach concentrations of 50 mg/l (Table 14).

Using the assumptions that a 5 day bleed/pump-back period is feasible for storage and bleed/pump-back, and that the loading rate to the final clarifiers is the most limiting design parameter, the volume of CSO sludge which can be handled at the treatment plant can be calculated. This volume can then be related to the percent of CSO area and CSO volume which can be treated using the existing dry-weather treatment plant for sludge handling. A plot of this information is included in Figure 6. It is apparent that as the treatment plant tends to the higher design capacity, less CSO sludge can be adequately handled (disregarding the negative impact of constant maximum loading conditions).

It is therefore apparent that the problems associated with bleed/pump-back to the dry-weather treatment plant are complex. If the initial transport problems can be eliminated or overcome, the effect of the sludges on the operation and efficiency of the dry-weather treatment plant must be carefully evaluated. The built-in safety factors for design can provide a certain amount of additional capacity, however, operating a peak flow due to bleed/pump-back of CSO sludges at all times is difficult and will adversely affect effluent quality.

EFFECT OF BLEED/PUMP-BACK OF DILUTE RESIDUALS FROM THE ON-SITE DEWATERING OF CSO TREATMENT SLUDGES ON THE DRY-WEATHER TREATMENT PLANT

Previous discussion has indicated overwhelmingly that bleed/pump-back of raw CSO treatment sludges is not practicable in most situations. Another alternative is to separately dewater (on-site) the raw CSO treatment sludges, ultimately dispose of the dewatered sludge and bleed/pump-back the dilute effluents from the dewatering steps to the dry-weather plant. The purpose of this discussion is to evaluate the effect of pumping back the dilute effluents from the CSO sludge dewatering processes to the dry-weather treatment plant.



lb/day/ft^2 x 4.88 = kg/day/m^2

Figure 6. Limiting percent of CSO area based on available capacity.

The only pertinent information uncovered in the literature (12) was based upon bench scale dewatering studies performed on raw CSO treatment sludges obtained from various CSO treatment sites throughout the country. The conclusions drawn from the study indicated that centrifugation alone or in combination with thickening and thickening followed by vacuum filtration were found to be the optimum sludge dewatering processes based on such criteria as performance, costs and space requirements.

Based upon our hypothetical dry-weather plant handling a design flow of 17.1×10^6 cu m/day (4,500 MGD) sewage and design solids load of 3.4×10^6 kg/day (7.6×10^6 lb/day), shown in Table 28 are the combined flows and solids anticipated from the bleed/pump-back of the dilute effluent arising from the dewatering of the CSO treatment sludges.

Assuming the range multiple of design flow and solids that a dry weather plant can handle is 1.5 to 3.0, examination of Table 28 shows that a hydraulic or solids overload would not be expected when the dilute effluents from dewatering CSO sludges are pumped back over a 24 hour period.

BOD, heavy metal, PCB and pesticide data on the dilute effluents from dewatering CSO sludges were not discovered in the literature, and therefore, no comment is made at this time regarding organic overload and toxicity to treatment due to heavy metals, PCB and pesticides caused by the bleed/pump-back of dilute effluents from dewatering CSO sludge to the dry-weather plant.

EFFECT OF CSO TREATMENT RESIDUALS BLEED/PUMP-BACK ON THE OPERATION AND PERFORMANCE OF THE DRY WEATHER SLUDGE HANDLING FACILITIES

Previous discussion has dealt with the effect of pumping back CSO residuals on the operation and performance of the dry-weather treatment plant. One of the by-products of the dry-weather treatment plant is the residual sludges arising from treatment which have to be handled and disposed of. The discussion which follows is concerned with the effect of pumping back CSO treatment residuals on the operation and performance of the dry weather sludge handling facilities.

Previous discussion regarding the bleed/pump-back of CSO treatment sludges to the treatment portion of the dry weather plant has shown that bleed/pump-back over a 24 hour period results in a gross solids overload on the treatment plant. Moreover, depending upon the existing dry weather operating organic loading on the secondary treatment plant, bleed/pump-back of the CSO treatment sludges may not be permissible or would have to be extended over periods of one to two weeks or more, which does not appear practical from the standpoint of having the capability of handling the sludge residuals from successive combined sewer overflows.

However, assuming the dry weather treatment plant could handle the pumped back CSO treatment sludges, or assuming for the moment that the CSO treatment sludges are bled/pumped-back directly to the dry-weather sludge handling facilities, what would be the effect on those sludge handling facilities?

TABLE 28. EFFECT OF BLEED/PUMP-BACK OF DILUTE EFFLUENTS FROM DEWATERING OF CSO SLUDGES ON DRY WEATHER TREATMENT PLANT HYDRAULIC AND SOLIDS LOAD

CSO Treatment Process	Raw CSO Sludge volumes		Dewatering Method Used	Dilute Effluents Bleed/Pump-Back					Bleed/Pump-Back + DWF			
	million cu m/day	MGD		Flow million cu m/day	Flow MGD	Solids mg/l	Solids kg/dayx10^{-6}	Solids lb/dayx10^{-6}	Flow million cu m/day	Flow MGD	Solids kg/dayx10^{-6}	Solids lb/dayx10^{-6}
Storage-Sedimentation	0.83	220	C	0.76	200	347	0.26	0.59	17.90	4730	3.70	8.14
Dissolved-Air Flotation	0.57	150	C	0.49	130	94	0.04	0.09	17.64	4660	3.47	7.65
Screening/DAF	4.50	1190	T-C	4.39	1160	1321	5.80	12.78	21.57	5690	9.23	20.34
Contact Stabilization	3.26	860	T-F	3.07	810	331	1.02	2.24	20.21	5340	4.45	9.80
Trickling Filter	0.64	170	T-C	0.64	170	170	0.11	0.24	17.79	4700	3.54	7.80

NOTE C = centrifugation alone

T-C = combination of thickening followed by centrifugation of the thickened sludge

T-F = combination of thickening followed by vacuum filtration of the thickened sludge

Shown in Table 8 are typical sludge volumes produced in a dry-weather plant. Primary sedimentation [2,440 cu m(gal.) sludge (5% solids) per million cu m (gal.) sewage treated] and waste activated [18,700 cu m (gal.) sludge (1% solids) per million cu m (gal.) sewage treated] sludges are pertinent to this discussion.

Sludge handling facilities are usually based upon the estimated sludge produced at average design flow (17). For our hypothetical dry-weather plant treating an average daily flow of 17.1×10^6 cu m/day (4,500 MGD) a primary sludge volume of 42,000 cu m/day (11.1 MGD) and a waste activated sludge volume of 320,000 cu m/day (84.7 MGD) may be expected to be handled by the dry-weather sludge handling facilities.

1. Hydraulic Loading Considerations

The daily design volume (primary plus activated) of sludge to be handled by the dry-weather sludge handling facilities is 363,000 cu m/day (96 MGD). Shown in Table 16 are the daily CSO treatment sludge volumes expected if the entire CSO were treated by each of the various CSO treatment methods investigated. Table 17 shows that the daily volume of CSO treatment sludges from each of the CSO treatment methods investigated is of a higher order of magnitude than the design daily dry-weather sludge anticipated, varying from 5.8×10^5 cu m/day (150 MGD) to 5.6×10^6 cu m/day (1480 MGD). The above information indicates that the addition of CSO treatment sludges to the dry-weather sludge handling facilities would result in drastically reducing the detention time of the various process elements in the sludge handling facilities.

Since detention time is one of the important factors in the performance of sludge handling processes (thickening, digestion, vacuum filtration, centrifugation, sand bed drying, etc.), it may be concluded that the CSO treatment sludge volume would hydraulically overload the dry-weather facilities, thereby, appreciably adversely affecting their performance. Additionally, the hydraulic overload may be expected to result in deteriorated by-products (such as thickener effluents, digester supernatants, filtrates, centrates, etc.) which are normally returned to the head end of the treatment plant and will result in overloading the treatment plant with fine solids, organics, nutrients, etc., thereby detrimentally affecting treatment plant performance.

2. Solids Loading Considerations

For our hypothetical dry-weather plant, the design dry weather solids to be handled (primary plus activated) are 5.3×10^6 kg/day (11.69×10^6 lb/day). Presented in Table 17 are the daily dry weight of CSO treatment sludge solids expected if the entire CSO were treated by each of the various CSO treatment methods investigated. Table 17 shows that the daily dry weight of CSO treatment sludge solids from each of the CSO treatment methods investigated is several times greater than that of the design daily dry weather solids anticipated, varying from 14.5×10^6 kg/day (31.9×10^6 lb/day) to 39.2×10^6 kg/day (86.4×10^6 lb/day).

The above information indicates that the addition of CSO treatment sludges to the dry-weather sludge handling facilities will drastically overload the various process elements comprising the sludge handling facilities from a solids standpoint. For example, those process elements whose equipment capacities are based on solids loading (see Tables 9—13) (such as thickening, filtration, lagooning, sand drying beds, centrifugation, etc.) would require 3 to 8 times additional capacity to handle the excess load. Digestion processes are more affected by organic and inert solids and the effect of CSO treatment sludges on digestion will be covered separately below.

3. Organic and Inert Solids Considerations

The organic content (as measured by volatile solids) of municipal sludges (primary sludge and waste activated sludge) is 65% on a dry solids basis (30). For our hypothetical dry-weather plant, the design dry weather total solids to be handled (primary plus waste activated) has been previously established at 5.3×10^6 kg/day (11.7×10^6 lb/day). The corresponding volatile solids content is 3.5×10^6 kg/day (7.6×10^6 lb/day). Presented in Table 29 are the daily dry weight of CSO treatment sludge volatile solids expected if the entire CSO were treated by each of the various CSO treatment methods investigated. From Table 29 it may be seen that the volatile solids content of the CSO sludges was significantly to appreciably lower than that for dry-weather municipal sludges. For the CSO treatment methods shown in Table 29, the higher volatile solids contents are observed for the sludges derived from the biological treatment methods. This was expected because the biological treatment methods were preceded by treatment steps which removed the major portion of the grit and inert solids present in the raw CSO. The physical and physical-chemical treatment methods shown in Table 29 treated raw CSO with little or no preliminary treatment for inert solids removal.

Examination of Table 29 and comparison with the hypothetical dry-weather municipal volatile solids loading, shows that the daily volatile solids rate from the CSO treatment methods varied from about 1.5 to 5.5 times the design dry-weather rate of 3.5×10^6 kg/day (7.6×10^6 lb/day) previously determined. It is apparent from this comparison that additional digestion facilities (aerobic and anaerobic) will be required to handle the CSO sludges by these treatment methods. These additional digestion facilities (either on-site or parallel to the DWF facilities) for handling the CSO sludges should be preceded by a grit removal step to reduce the possibility of grit and other inert solids from settling in the digesters and occupying valuable space.

4. Toxicity to Treatment

Pertinent to this discussion is the determination of any toxic effect of heavy metals in the CSO sludges to treatment in the dry-weather sludge handling facilities. The toxic effect, if any, would manifest itself in the biological treatment portions of the sludge handling systems, such as in the aerobic or anaerobic sludge digestion processes.

TABLE 29. VOLATILE SOLIDS CONTENT OF SLUDGES FROM VARIOUS CSO TREATMENT PROCESSES

CSO Treatment Process	Sludge Characteristics						
	Total Solids		Percent Volatile Solids	Volatile Solids		Inert Solids	
	kg/day $\times 10^{-6}$	lb/day $\times 10^{-6}$		kg/day $\times 10^{-6}$	lb/day $\times 10^{-6}$	kg/day $\times 10^{-6}$	lb/day $\times 10^{-6}$
Storage-Sedimentation	14.5	31.9	46.9	6.8	15.0	7.7	16.9
Dissolved-Air Flotation	15.6	34.4	30.9	4.8	10.6	10.8	23.8
Screening/DAF	37.9	83.4	34.2	12.9	28.5	24.9	54.9
Microscreening	39.2	86.4	29.1	11.4	25.1	27.8	61.3
Contact Stabilization	32.6	71.7	58.7	19.1	42.1	13.4	29.6
Trickling Filter	20.6	45.4	60.8	12.5	27.6	8.1	17.8

Previous discussion has indicated that it is impractical to direct the CSO treatment sludges to the dry-weather sludge handling facilities because this would cause a gross hydraulic, organic and solids overload of those facilities. However, for purposes of this discussion, for those isolated cases where the dry-weather sludge handling facilities could handle the CSO sludges, what would be the effect with regard to toxicity of digestion sludge treatment?

Shown in Table 22 are the effects of various heavy metal concentrations on aerobic and anaerobic biological treatment processes. The data in Table 22 indicate, for example, that copper concentrations greater than 5 mg/l and zinc concentrations greater than 10 mg/l will detrimentally affect anaerobic sludge digestion. Another source (32) indicates that soluble heavy metal concentrations greater than 1 mg/l are toxic to anaerobic digestion. Still another source (31) indicated that raw sludge copper concentrations of 14.3, 27.7 and 60.6 mg/l for three sewage treatment plants in Ohio did not adversely affect anaerobic sludge digestion or gas production. The information presented above appears to be in conflict. It is indicated that the concentration at which a substance starts to exert a toxic effect is difficult to define because it can be modified by antagonism, synergism and acclimation. Moreover, in the case of intermittently treating CSO treatment sludges in dry weather sludge handling facilities, the digesters act as equalization basins to dilute any heavy metal concentration present in the CSO treatment sludges and thereby ameliorate any potential heavy metal toxic effect.

Presented in Table 23 are the heavy metal concentrations found in the sludges from various CSO treatment processes. It was observed that the heavy metal concentrations in the CSO treatment sludges were significant and in some cases, such as for zinc and copper, were generally excessive (based on the allowable values in Table 22). Moreover, the data showed that the heavy metal concentrations of the CSO sludges from biotreatment processes (contact stabilization and trickling filteration) were appreciably higher than those for the sludges from the physical and physical-chemical CSO treatment processes.

That CSO treatment sludges may be handled intermittently in dry-weather digesters (where applicable and all other things being equal) in spite of high heavy metal concentrations is exemplified by the Kenosha, Wisconsin sewage treatment plant which has a 75,700 cu m/day (20 MGD) dry-weather plant and a 75,700 cu m/day (20 MGD) wet weather contact stabilization plant. The relatively high heavy metal concentrations in the Kenosha CSO contact stabilization waste sludge are shown in Table 23 (zinc, 71.5 mg/l; copper 14.5 mg/l). The intermittent handling of this wet weather sludge by the Kenosha anaerobic digesters has been satisfactory with no apparent adverse effect on digestion or gas production.

Handling of CSO treatment sludges in parallel digester facilities at the dry-weather plant is another story because essentially no dilution or equalization is obtained with dry-weather sludge. It is questionable whether digestion should be used in the CSO sludge handling scheme when

CSO treatment sludges are to be treated on-site or in parallel digester facilities at the dry-weather plant.

In any event, if toxicity is suspected for a given application, potential solutions to toxicity problems should be evaluated in laboratory or pilot digesters.

Alternatively, a promising method for the rapid stabilization of difficult-to-handle sludges, such as CSO treatment sludges, is lime stabilization, and it is recommended that further investigation of this method be conducted.

5. Treatment Efficiency

It is readily evident from previous discussion that directing the CSO treatment sludges to the dry-weather sludge handling facilities will grossly overload those facilities from a hydraulic, organic and inert solids standpoint. These gross overloads will detrimentally affect the dewatering and stabilization performance and treatment efficiency of the dry-weather sludge handling facilities. The downgrading in treatment efficiency would be manifested in poorly stabilized sludge for disposal and grossly deteriorated thickener effluents, filtrates, supernatants, etc. for recirculation back to the dry-weather plant.

As previously recommended, alternative on-site treatment methods, such as lime stabilization, should be investigated for handling CSO treatment sludges.

EFFECT OF BLEED/PUMP-BACK OF THE DILUTE RESIDUALS FROM THE ON-SITE DEWATERING OF CSO TREATMENT SLUDGES ON THE DRY-WEATHER SLUDGE HANDLING FACILITIES

From previous discussion, it appeared that from a hydraulic and solids aspect the dry-weather treatment plant would be able to handle the bleed/pump-back of dilute residuals from the on-site dewatering of CSO treatment sludges. However, data was not available to evaluate the effect of dilute effluents bleed/pump-back on organic overload or toxicity to treatment in the dry-weather plant. This section allows evaluation of the separate effect of pump back of the dilute CSO sludge dewatering residuals on the dry-weather treatment plant sludge handling facilities.

Shown in Table 30 are the flows and characteristics of the dilute effluents from the dewatering of the CSO sludges pumped back to the hypothetical dry-weather plant. It may be noted in Table 28 that only solids data was available from the dilute effluents pumped back. It may also be seen from Table 28 that the strength (solids) of the dilute effluents varied widely with the CSO treatment process from which they were derived. Some of the dilute effluents were stronger than domestic sewage and some were weaker. The suspended solids content of sewage has previously been assumed at 200 mg/l (9). In order to estimate the quantity of sludge produced from the treatment of the dilute effluents bled/pumped-back, the dilute effluent flows shown in